

A criticism of "gas mode" reinterpretations of the Michelson-Morley and similar experiments.

Daniel Shanahan

18 Sommersea Drive, Raby Bay, Queensland 4163, Australia

Abstract

It has been argued by R. T. Cahill and others that a Michelson interferometer in "gas mode" - in which the light paths are through an included gaseous medium - are able to detect and have detected an absolute frame of reference. It is shown here that this argument supposes incorrectly that the reduced velocity of light in gas is an observer-independent invariant. This velocity is not invariant, but given in a frame with respect to which the interferometer moves with velocity v by the usual relativistic formula for the addition of velocities, these being in this case the velocity v and the reduced velocity of light in the inertial frame of the interferometer. It is suggested nonetheless that though the absolute frame urged by Cahill may be undetectable, there are persuasive grounds for considering the alternative Lorentzian Relativity that did suppose the existence of such a frame.

(This is an updating of a note that appeared in the March/April 2006 issue of *Australian Physics* [1]. A similar criticism of Cahill's "gas mode" analysis has been given by Sfarti [2].)

R. T. Cahill has argued that the Michelson-Morley experiment of 1887 [3] did not produce the null result generally supposed (see Cahill and Kitto [4], and Cahill [5] to [13]). This note draws attention to an apparent flaw in that argument, and in similar proposals by Consoli et al [14] to [17] and Demjanov [18] [19]. However, it is also suggested here that whether or not the absolute frame urged by these investigators is detectable, there exist compelling reasons for considering the alternative Lorentzian approach to relativity that did suppose such a frame.

Fringe shifts were observed by Michelson and Morley, but these were much smaller than those expected from the presumed velocity of the interferometer through the aether. Cahill contends that these shifts were consistent nonetheless with the passage through an absolute frame of reference of an interferometer in "gas mode" - an interferometer in which the light paths are not through vacuum but through contained air or other gaseous medium.

The null result reported by Michelson and Morley has been confirmed by later experiments of greater precision (see, for instance, Refs. [20] to [25]). Moreover, the modern view of these experiments, or at least the prevailing modern view, is that any aether or other absolute frame of reference is likely to remain undetected because of the covariance of the Lorentz Transformation (LT). That seems to have been the conclusion reached eventually by Lorentz himself [26], as also by Poincaré who was the first to describe the group theoretic properties underlying that covariance [27].

Cahill accepts that such a frame will not be revealed by an interferometer in which the light paths are through vacuum. In that case, differences in travel time will be countered exactly by Fitzgerald-Lorentz contraction. He argues, however, that where, as in Michelson-Morley and similar experiments, the light paths are through contained air, the balancing is not exact. Because of the diminished phase velocity of light in gas, small phase shifts will occur of the order of magnitude of those reported.

This "gas mode" analysis and the theory of "process physics" to which it has led [5] have gained some support in the literature (see Refs. [14] to [17], and [28]). Indeed, Cahill's reasoning has been extended to the "vacuum mode" by Consoli et al by relying on vacuum fluctuations and gravitationally induced refraction effects [14] to [17]. Cahill has himself proposed that noise in interference fringe readings could be evidence of gravity waves [8] to [13].

These proposals assume incorrectly that, like the velocity c of light in vacuum, the reduced phase velocity V of light through gas is an invariant. It is only to an observer in the inertial frame of the interferometer that the refracted light has the particular velocity that has been supposed by Cahill. In considering the magnitude of this velocity from another inertial frame, one must apply the relativistic formula for the addition of velocities, those velocities being in this case, the velocity of the interferometer with respect to the other frame, and the phase velocity V of the signal with respect to the gas entrapped within the interferometer. (See Shanahan [1], and Sfarti [2]).

The relativistic addition formula, given by Einstein in 1905 [29], was applied by von Laue as early as 1907 in calculating the velocity of light in a moving medium [30]. It is perhaps ironic that, as recounted recently by Janssen [31], the moving medium was in that case the aether - von Laue applied the addition formula in calculating the effect of Fresnel drag.

As Janssen has also mentioned, von Laue's calculation was subsequently cited by Einstein in a text on relativity published in Germany in 1917 [32]. It is also discussed in Pauli's well-known work on relativity [33], at p. 17, while the application of the addition formula to the velocity of light in a moving medium is routinely mentioned in modern texts on optics and relativity, for instance, Resnick [34], at p. 80, Rindler [35], at p. 44, and Jenkins and White [36], at p 421.

Let us suppose (see Fig. 1) that the Michelson interferometer is moving with velocity v with respect to some absolute frame of reference, and that it is only in this frame that light is not only observed to have, but in fact has, the velocity c in vacuum. Where the interferometer arm is aligned in parallel with

the direction of v , the formula for the addition of velocities gives,

$$V_{A_1B} = \frac{V + v}{1 + Vv/c^2}, \quad (1)$$

for the forward path, and

$$V_{BA_2} = \frac{V - v}{1 - Vv/c^2}, \quad (2)$$

for the return path.

As observed from the absolute frame, the arm length L is relativistically contracted to L/γ , where γ is the usual Lorentz factor,

$$(1 - \frac{v^2}{c^2})^{-1/2}$$

so that the time for a round trip as considered from that frame becomes,

$$\begin{aligned} t_{A_1BA_2} &= \frac{L/\gamma}{(V + v)/(1 + Vv/c^2) - v} + \frac{L/\gamma}{(V - v)/(1 - Vv/c^2) + v} \\ &= 2\gamma L/V \end{aligned}$$

In the other, the light paths are inclined at an angle to the direction of travel. However we need only consider those components of phase velocity and path length normal to the direction of travel (or see equivalently Sarti [2], Eqn. (2.6) et seq.). The time-dilated phase velocity is V/γ , while the corresponding component of path length is simply L . Thus,

$$t_{A_1C} = t_{CA_2} = \gamma L/V,$$

from which,

$$t_{A_1BA_2} - t_{A_1CA_2} = 0,$$

for all V , ensuring a null result whatever the gas within the interferometer.

But instead of the relativistically composed velocities (1) and (2), Cahill takes their simple Galilean equivalents, that is,

$$V_{A_1B} = V + v,$$

for the forward path, and

$$V_{BA_2} = V - v,$$

for the return path. (See, for example, the discussion preceding Eqn. (16) in Cahill [8], at p. 79).

Proceeding in this way, he finds, after some algebra, a difference in travel times,

$$t_{A_1BA_2} - t_{A_1CA_2} = \frac{(n^2 - 1)L}{c} \frac{v^2}{c^2} + O(\frac{v^4}{c^4}) + \dots,$$

from which he naturally, but incorrectly, concludes that a Michelson interferometer in gas mode may act as a detector of absolute motion.

The assumption that the phase velocity V is invariant invites the further criticism that the same effective index of refraction for the contained gas has been assumed throughout the experiment, whatever the orientation and velocity of the apparatus. Refractive index is a function of density, and from the standpoint of an observer in the absolute frame, the density of the gas encountered by the light signal will depend on whether it is moving with or against or transversely to the movement of the gas.

However, the null results reported from such experiments do not have today the significance they had in 1887. A clearly established *positive* result would compel a reconsideration of the invariability of the laws of physics and presumably some surprise that Nature is not quite as elegant as the covariance of the LT would suggest. But, as noticed above, a null result does not itself preclude the existence of an aether or other absolute frame of reference (or theories of gravity that presuppose such an aether).

Several writers (notably Bell [37], but see also, for example, Miller [38] and Nelson [39]) have stressed the pedagogical merits of studying not only the Special Relativity of Einstein, to whom the existence of an aether was "superfluous", but also the earlier approach of Lorentz, Larmor and Poincaré, who did suppose a preferred frame and aether. Briefly stated, the distinction between Einstein's theory and what is commonly called Lorentzian Relativity is that the former explains the LT as a physical transformation of spacetime and the latter from changes in the structure of matter as it suffers a boost from one inertial frame to another (see generally Shanahan [40]).

Following the publication of his famous paper of 1905 [29], Einstein's theory eventually displaced the older Lorentzian approach. Lorentz had struggled to explain why all aspects of Nature transform in like manner, a problem compounded by the apparent inconsistency of Lorentz's essentially classical electromagnetic modelling with the new quantum mechanics. His explanations of the various changes described by the LT also seemed piecemeal and ad hoc - lacking in the kind of unifying principle supplied by Einstein's "postulate" that the laws of physics must appear the same for all observers, a principle that was to find elegant expression in Minkowski's geometrical treatment of spacetime [41]. And of course special relativity was naturally seen as precursor to Einstein's success with general relativity (GR).

Yet for all its elegance and economy, there is something elusive in Einstein's theory. There seems little doubt that the LT is an accurate description of the changes of length, time and simultaneity *observed* on a change of inertial frame. But the notion that the LT describes some actual (as distinct from observed) change in space really makes no sense at all. No such difficulty arises in GR where a change in the metric affects in like manner all that occupies the part of space in question. But how are we to comprehend that space is able to contract in one way for one particle and in a different way for another moving relatively to the first, albeit that the two (or at least their correspondingly contracted fields) could be occupying the very same piece of space? And are we to suppose

that when an astronaut observes the contraction of the constellations as she accelerates through space, she really believes that the stars are closing ranks about her?

As the astronaut suffers a boost from one inertial frame to another, the only relevant physical changes actually occurring are in her and her spacecraft. Neither the stars nor the space occupied by the stars can have changed in any relevant way. It must be some change in the astronaut that not only causes her to appear transformed to others, but induces in that astronaut the illusion that it is not she and her space craft that has changed, but all else about her. This then is the Lorentzian view of things - the explanation of the LT as a consequence of changes in matter as it changes inertial frame.

On this view, it becomes necessary to look beyond the symmetry of the metric and ask questions that are precluded in Einstein's theory. Why are the laws of physics the same for all observers? And what after all is the origin of the observed metric? If the LT describes not actual, but merely perceived, changes in space and time, the invariance of the laws of physics cannot provide the unifying principle suggested by special relativity. Nor can the Minkowski metric be the source of that invariance for it must itself be seen as a kind of illusion induced by changes occurring in the observer.

The proposition that the metric is not given but emergent - that it supervenes on matter - has been argued forcefully (see Brown [42] and Brown and Pooley [43]), and just as strongly resisted (see, for instance, Janssen [31] [44], Norton [45] and Nerlich [46]). But that resistance has been largely grounded on the simplicity and elegance of Einstein's theory. Once it is realized that the LT describes perceived rather than actual changes in space (or spacetime), the LT, the metric, and the invariance of physical laws, must all be seen as having their origin in some even more fundamental property of Nature.

A hint of a deeper unifying principle was given in 1925 when de Broglie proposed that matter shares the wave-like characteristics of light [47], thereby uncovering, as Einstein put it, "a corner of the great veil". It then became possible to argue that everything in Nature transforms in like manner because it is constituted in like manner from the same underlying wave-like influences.

It can be shown that the merits of such an Lorentzian approach are far more than pedagogical. A compelling advantage is the emergence of the otherwise anomalous de Broglie wave, not as the independent wave generally supposed, but as a modulation defining the dephasing of the underlying wave structure in the direction of travel (as seems to have been first noticed in a different context by R. Horodecki [48], see also Macken [49], and other references in Shanahan [40]).

Considered as a modulation, the superluminal velocity of the de Broglie wave is no longer that of energy transport and need not be explained away by the awkward device of recovering the classical velocity of the particle from the group velocity of a packet of such de Broglie waves. This interpretation of the de Broglie wave sheds light in turn on the role of the wave in quantization and in the Schrödinger and Dirac Equations, and explains the relevance of the de Broglie wave number to the optical properties of massive particles. The dephasing

defined by the modulation becomes the underlying physical explanation of the failure of simultaneity that is perhaps the most counter-intuitive aspect of SR.

These matters are discussed in more detail in Ref. [40].

References

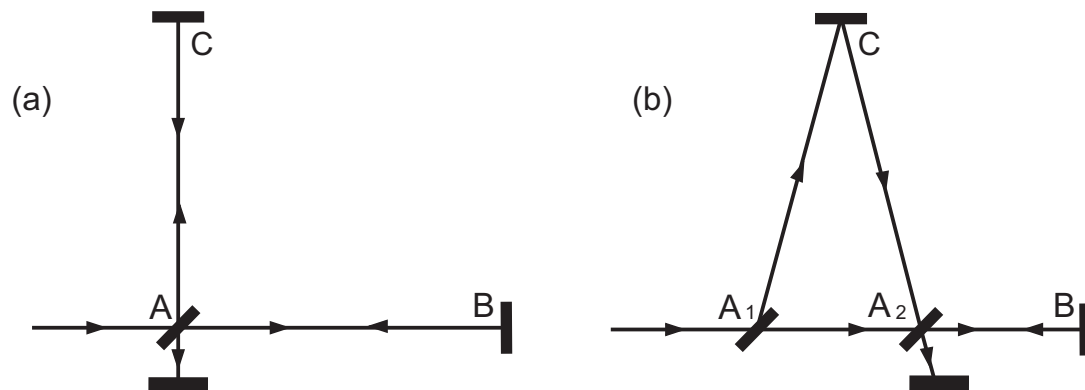
- [1] D. Shanahan, *Australian Physics*, Mar./Apr. (2006)
- [2] A. Sfarti, Corrected theory of the reenactments of the Michelson-Morley experiment in non-vacuum media, *Rom. J. Phys.* **52**, 533 (2007)
- [3] A. A. Michelson and E. W. Morley, On the Relative Motion of the Earth and the Luminiferous ether, *Am. J. Sc.* **34**, 333 (1887)
- [4] R. T. Cahill, and K. Kitto, Michelson-Morley Experiments Revisited and the Cosmic Background Radiation Preferred Frame. *Apeiron* **10**, 104 (2003)
- [5] R. T. Cahill, *Process Physics: From Information Theory to Quantum Space and Matter*, Nova Science, New York (2005)
- [6] R. T. Cahill, The Michelson and Morley 1887 Experiment and the Discovery of Absolute Motion, *Prog. Phys.* **3**, 25 (2005)
- [7] R. T. Cahill, *Australian Physics*, Jan./Feb. (2006)
- [8] R. T. Cahill, A New Light-Speed Anisotropy Experiment: Absolute Motion and Gravitational Waves Detected, *Prog. Phys.* **4**, 73 (2006)
- [9] R. T. Cahill, Dynamical 3-Space: A Review, in M. Duffy and J. Lévy eds., *Ether space-time and cosmology: New insights into a key physical medium*, Apeiron (2009)
- [10] R. T. Cahill, Resolving Spacecraft Earth-Flyby Anomalies with Measured Light Speed Anisotropy, *Prog. Phys.* **4**, 9 (2008)
- [11] R. T. Cahill, Unravelling Lorentz Covariance and the Spacetime Formalism, *Prog. Phys.* **4**, 19 (2008)
- [12] R. T. Cahill, Combining NASA/JPL One-way Optical-fibre Light-Speed Data with Spacecraft Earth-Flyby Doppler-Shift Data to Characterize 3-Space Flow, *Prog. Phys.* **4**, 50 (2009)
- [13] R. T. Cahill, Lunar Laser-Ranging Detection of Light Speed Anisotropy and Gravitational Waves, arXiv: 1001.2358 [physics.gen-ph] (2010)
- [14] M. Consoli, A. Pagano, and L. Pappalardo, *Phys. Lett. A* **318**, 292 (2003)
- [15] M. Consoli and E. Costanzo, The motion of the Solar System and the Michelson-Morley experiment, arXiv: astro-ph/0311576 (2003)

- [16] M. Consoli and E. Costanzo, From classical to modern ether-drift experiments: the narrow window for a preferred frame, *Phys. Lett. A*, **333**, 355 (2004)
- [17] M. Consoli and E. Costanzo, Old and new ether-drift experiments: a sharp test for a preferred frame, *N. Cimento B*119, 393 (2004)
- [18] V. V. Demjanov, Physical interpretation of the fringe shift measured on Michelson interferometer in optical media, *Phys. Lett. A* **374**, 1110 (2010)
- [19] V. V. Demjanov, What and how the Michelson interferometer measures, arXiv:1003.2899v6 [phys.gen-ph] (2010)
- [20] C. Braxmaier, H. Müller, O. Pradl, J. Mlynek, A. Peters, and S. Schiller, Tests of Relativity Using a Cryogenic Optical Resonator, *Phys. Rev. Lett.* **88**, 010401 (2002)
- [21] P. Wolf, S. Bize, A. Clairon, A. N. Luiten, G. Santarelli, and M. E. Tobar, Tests of Lorentz Invariance using a Microwave Resonator, *Phys. Rev. Lett.* **90**, 060402 (2003)
- [22] J. A. Lipa, J. A. Nissen, S. Wang, D. A. Stricker, and D. Avaloff, New Limit on Signals of Lorentz Violation in Electrodynamics”, *Phys. Rev. Lett.* **90**, 060403 (2003).
- [23] H. Müller, P. L. Stanwix, M. E. Tobar, E. Ivanov, P. Wolf, S. Herrmann, A. Senger, E. V. Kovalchuk, and A. Peters, ”Relativity tests by complementary rotating Michelson–Morley experiments”. *Phys. Rev. Lett.* **99**, 050401 (2007)
- [24] C. Eisele, A. Y. Nevsky, and S. Schiller, Laboratory test of the isotropy of light propagation at the 10-17 level, *Phys. Rev. Lett.* **103**, 090401 (2009)
- [25] S. Herrmann, A. Senger, K. Möhle, M. Nagel, E. V. Kovalchuk, and A. Peters, Rotating optical cavity experiment testing Lorentz invariance at the 10-17 level, *Phys. Rev. D* **80**, 105011 (2009)
- [26] H. A. Lorentz, *The Theory of Electrons*, Teubner, Leipzig (1916)
- [27] H. Poincaré, Sur la dynamique de l’électron, *Rendiconti del Circolo matematico di Palermo* **21**, 129 (1906)
- [28] H. Eckhardt, An Alternative Hypothesis for Special Relativity, *Prog. Phys.* **2**, 56 (2009)
- [29] A. Einstein, Zur elektrodynamik bewegter körper, *Ann. Phys.* **17**, 891 (1905). English trans., On the electrodynamics of moving bodies, in H. A. Lorentz, A. Einstein, H. Minkowski, H. Weyl, *The Principle of Relativity*, Methuen, London (1923)

- [30] M. von Laue, Die Mitführung des Lichtes durch bewegte Körper nach dem Relativitätsprinzip, *Ann. Phys.* **23**, 989 (1907)
- [31] M. Janssen, Drawing the line between kinematics and dynamics in special relativity, *Studies in History and Philosophy of Modern Physics* **40**, 26 (2009)
- [32] A. Einstein, *Über die spezielle und allgemeine Relativitätstheorie (gemeinverständlich)*, Vieweg, Braunschweig (1920), English trans., *Relativity*, Crown, New York (1961)
- [33] W. Pauli, *Theory of Relativity*, Dover, New York (1958)
- [34] R. Resnick, *Introduction to Special Relativity*, Wiley, New York (1968)
- [35] W. Rindler, *Introduction to Special Relativity*, Oxford, New York (1982)
- [36] F. A. Jenkins and H. A. White, *Fundamentals of Optics*, 4th Ed. McGraw-Hill, Singapore (1981)
- [37] J. S. Bell, How to teach Special Relativity, *Prog. Sci. Cult.* 1, 2 (1976), reprinted in: *Speakable and Unspeakable in Quantum Mechanics*, revised edn., Cambridge University Press, Cambridge (2004)
- [38] D. J. Miller, A constructive approach to the special theory of relativity, *Am. J. Phys.* **78**, 633 (2010)
- [39] W. M. Nelson, A wave-centric view of special relativity, arXiv:1305.3022 physics.class-ph (2013)
- [40] D. Shanahan, A Case for Lorentzian Relativity, *Found. Phys.* **44**, 349 (2014) (DOI 10.1007/s10701-013-9765-x)
- [41] H. Minkowski, Raum und Zeit, *Phys. Zeits.* **10**, 104 (1909), English trans.: Space and time, in H. A. Lorentz, A. Einstein, H. Minkowski, H. Weyl, *The Principle of Relativity*, Methuen, London (1923)
- [42] H. S. Brown, *Physical Relativity*, Oxford University Press, Oxford (2005)
- [43] H. S. Brown and O. Pooley, Minkowski space-time: a glorious non-entity, in D. Dieks (ed.), *The Ontology of Spacetime*, Elsevier, Amsterdam (2006)
- [44] M. Janssen, Reconsidering a Scientific Revolution: The Case of Einstein *versus* Lorentz, *Phys. Perspect.* **4**, 421 (2002)
- [45] J. D. Norton, Why Constructive Relativity Fails, *Brit. J. Phil. Sci.* **59**, 821(2008)
- [46] G. Nerlich, Bell's 'Lorentzian Pedagogy': A Bad Education [preprint] philsci-archive.pitt.edu/5454/1/Bell.pdf (2010)

- [47] L. de Broglie, Ph. D. Thesis, Recherches sur la théorie des quanta. Ann. de Phys. (10) **3**, 22 (1925). English trans., Researches on the quantum theory, in Ann. Fond. Louis de Broglie **17**, 92 (1992)
- [48] R. Horodecki, Information Concept of the Aether and its application in the Relativistic Wave Mechanics and Quantum Cybernetics, in L. Kostro, A. Poslewnik, J. Pykacz, and M. Żukowski, Eds., *Problems in Quantum Physics, Gdansk '87*, World Scientific, Singapore (1987)
- [49] J. A. Macken, *The Universe is Only Spacetime*, <http://onlyspacetime.com/>

Fig. 1



Light paths within a Michelson interferometer, when the interferometer is
(a) stationary with respect to a supposed absolute frame, and
(b) moving at velocity v with respect to that frame.